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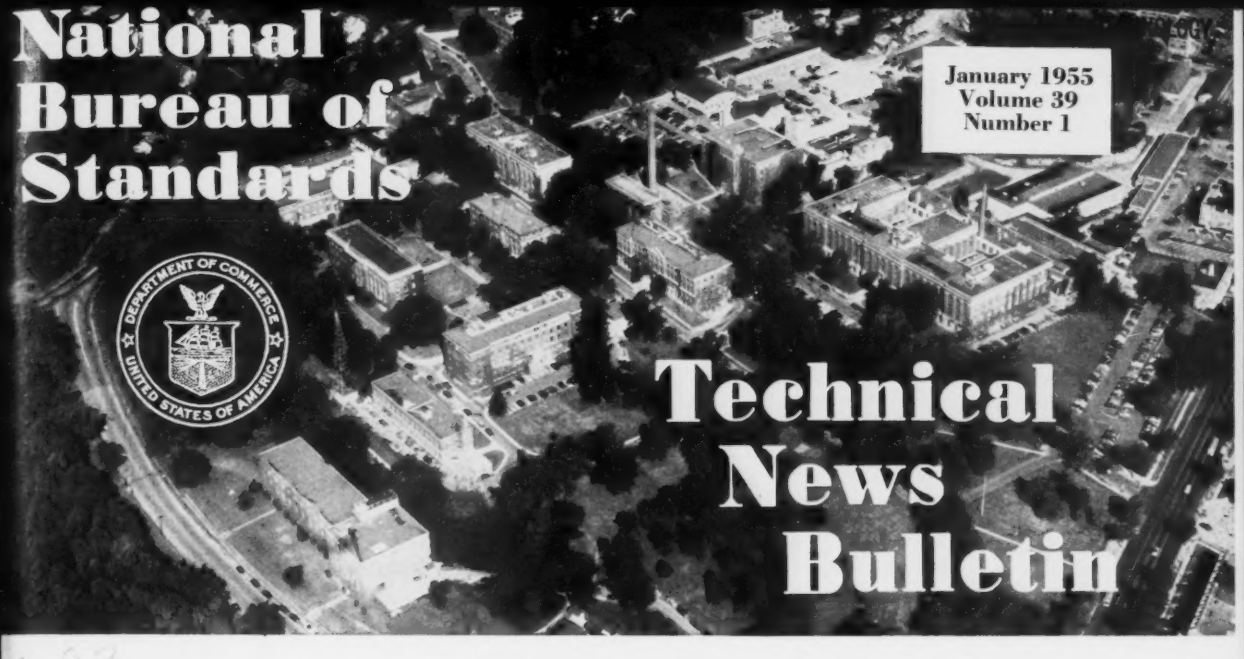

Technical News Bulletin

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DETROIT

Velocity of Light Redetermined

Higher Values Confirmed

TWO new determinations of the velocity of light have been made by National Bureau of Standard scientists. Although carried out independently by widely different methods, the two determinations give precise values that are in close agreement. They also provide confirmation for the higher values of electromagnetic wave velocity that have been consistently obtained by microwave measurements since World War II.

In one method, the velocity of light was determined from measurement of the molecular constants of carbon monoxide by infrared spectroscopy. This work was carried out in the Bureau's Washington laboratories by E. K. Plyler, L. R. Blaine, and W. S. Connor. The other determination made use of phase-shift measurements on very-high-frequency radio waves to obtain their velocity of propagation. These measurements were made with a radio interferometer by E. F. Florman, of the NBS Boulder (Colo.) Laboratories, on a dry lake bed in southeastern Arizona. The Bureau's statistical engineering laboratory cooperated with both groups in analyzing the resulting data, and the NBS high-speed electronic computer, SEAC, aided in the computations.

The velocity of electromagnetic waves has been a subject of investigation for many years. In the period preceding World War II, the value 299,776 ±4 kilometers per second [1] was generally accepted as an average of the findings of the various laboratories. However, since the war higher values have been obtained by most investigators, largely through measurement of the velocity of propagation of microwaves. Consideration of this more recent work has led to an average value [2] of 299,793 ±1 km/sec. The results obtained by the Bureau give 299,792 ±6 km/sec by the molecular constants method and 299,795.1 ±3.1 km/sec by the radio interferometer. They thus provide independent confirmation of the higher values obtained in other laboratories since World War II.

Molecular Constants Method

The molecular constants method was originally suggested by Dr. A. E. Douglas of Ottawa, Canada. As applied at the Bureau it involved measurement of the frequencies not only of lines in the infrared absorption spectrum of CO but also of infrared emission spectral lines obtained when CO is produced in the flame of a burning gas. Spectral lines corresponding to the rotational states only of the excited CO molecule were already available from microwave spectroscopy. The Bureau measured other lines corresponding to both vibrational and rotational states by infrared spectroscopy. The experimentally determined frequencies of the spectral lines were then used to calculate values of the molecular constants of CO which occur in theoretical formulas for the frequencies. The

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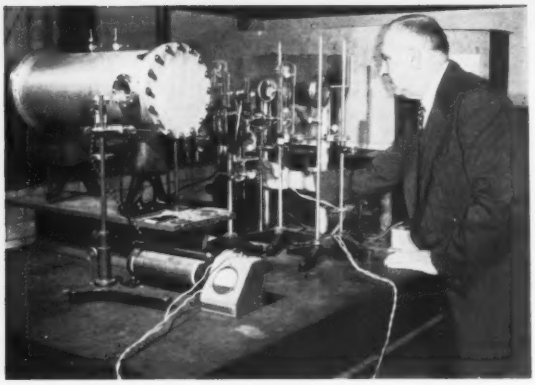


Apparatus used in determining the velocity of light by infrared measurements on the carbon monoxide molecule. Infrared source at left was used with adjacent carbon monoxide absorption cell to measure wavelengths of rotational lines in CO absorption spectrum. High precision required in determining frequencies of the spectral lines was made possible by grating spectrometer (enclosure, background) designed by E. K. Plyler, chief of the Bureau's radiometry laboratory. A Fabry-Perot interferometer (center) provided a comparison spectrum in measurements on the rotational-vibrational lines in the CO spectrum.

same molecular constants were obtained in both the infrared and microwave equations, but they were in different units: the microwave constants were in megacycles per second while the infrared constants were in reciprocal centimeters. Thus, the velocity of light could be calculated by taking the ratios of corresponding molecular constants.

The precision of this determination was due in large part to the selection of the CO spectrum for investigation. This spectrum has many spectral lines (both absorption and emission), from which molecular constants can be obtained. Also, the use of flame spectra made for greater precision by providing relatively large values of the rotational quantum number J, which occurs in higher powers in the infrared equations.

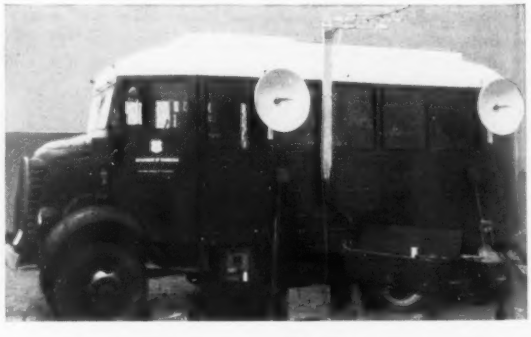
In the course of the experimental work, the wavelengths of 43 rotational lines in the CO absorption band at 4.67 μ were precisely measured using a grating spectrometer and an absorption cell. Fifteen lines in the emission spectrum of CO were also determined. In order to measure the rotational-vibrational band at 4.67 μ to high precision, the fringes of a Fabry-Perot interferometer were used for a comparison spectrum. The fringes were of visible white light in the region from 5000 to 6000 A, and they were detected in higher orders of the grating with a photomultiplier and an accompanying amplifier. The carbon monoxide lines were detected with a cooled lead-tellurium cell. The wave numbers of the fringes were determined in reference to the absorption lines by superposing on the recorded fringe system higher orders of emission lines of xenon, which were detected by the lead-tellurium cell. At low pressures of CO, the lines were sufficiently intense to measure to $J=23$ in the R branch and to $J=28$ in the P branch. However, when a torch burning a methane-oxygen mixture was used to produce CO, the emission lines from $J=32$ to $J=52$ in the P branch could be measured.

The resulting data were analyzed in the Bureau's statistical engineering laboratory by the method of least squares. The theoretical formula for the frequency in terms of molecular constants was fitted to each set of experimental data, and best estimates for the constants were obtained. The estimated standard deviation (± 6 km/sec) in the final value for the velocity of light includes an allowance for an absolute error as well as an estimate based upon the spread in the observed data.

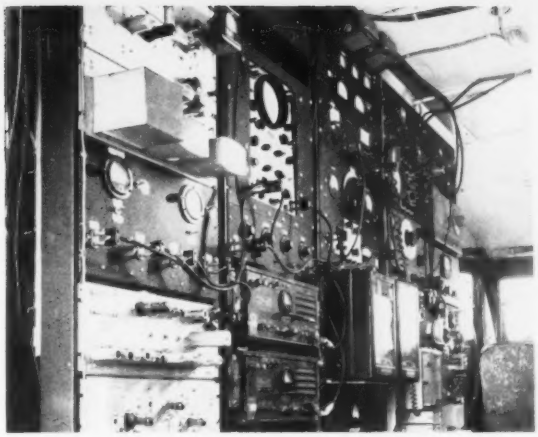
Radio-Interferometer Method

The radio-interferometer measurements were carried out on a dry lake bed in order to obtain a very flat surface completely devoid of vegetation for a distance of five miles or more. Essentially the method involved accurate determination of the wavelength of radio waves of a given frequency by measurement of a phase shift. After correction for various environmental factors, this wavelength was multiplied by the frequency of the radiation to obtain the velocity of electromagnetic waves. A radiofrequency in the VHF range—172.8 megacycles—was employed to avoid sky-wave interference, to minimize ground effects, and to reduce the physical size of the measuring system to dimensions convenient for standard distance-survey techniques.

Two receiving antennas accurately spaced 1.500 meters apart were used. By varying the position of the transmitter over a path which half-way encircled the two receiving antennas, the phase difference between the receivers was made to change. The wavelength of the radio waves was then calculated by dividing the accurately known distance between the receiving antennas by one-half the total change in phase difference.



Control truck used by NBS in radio-interferometer measurements of the velocity of electromagnetic waves. Truck contains equipment for monitoring frequencies and measuring phase changes. Antennas used with these systems are visible externally.



Interior view of the control truck. Oscilloscope in second rack from left is used to monitor phase changes. The precise results of the NBS experiments provide additional confirmation for the higher values of the velocity of light that have been obtained by other methods since World War II. In addition to the control truck, the system employed four manually operated stations for transmitters and receivers.

Even though the radio waves were transmitted over a flat surface, the value of wavelength thus determined was affected by the presence of the ground. It was also affected by the atmosphere through which the waves had to travel since the velocity of propagation of radio waves depends on the index of refraction of the air. Thus, to obtain the "free-space" wavelength—that is, the wavelength in vacuum—it was necessary to correct for ground effects and for the index of refraction of the air. Accurately known ground constants were used to adjust for ground effects while the index of refraction of the air was calculated as a function of temperature, pressure, and relative humidity.

In practice, transportation of the radio transmitter about the system was avoided by using two transmitters of the same frequency located on the extension of the line through the receiving points; the change in phase difference at the two receiving points was then noted when transmission was switched from one transmitter to the other. The only possible source of ambiguity in this experimental arrangement was uncertainty as to the number of 360-degree phase changes involved in the shift. This uncertainty was resolved at the start of the measurements by moving one transmitter across exactly one-half of the equiphase contours between the two transmitter positions and noting the change in phase which occurred between the signals at the receiving points.

For convenience, the actual phase measurement was made at an audiofrequency rather than the radiofrequency used for transmission. The audiofrequency was obtained by heterodyning the radiofrequency signal with another signal differing in frequency from the first by 1 kilocycle. The phase changes between the resulting audio signals at the receiving points are identical to the phase changes between the original radiofrequency signals.

Both the transmitting radiofrequency and the 1-kc heterodyne audio signal frequency were monitored and adjusted against a 100-kc crystal oscillator. The frequency of the oscillator was periodically checked and adjusted to 1 part in 10 million by comparing either its 50th or 100th harmonic with either the 5- or 10-Mc signal, respectively, broadcast by NBS radio station WWV.

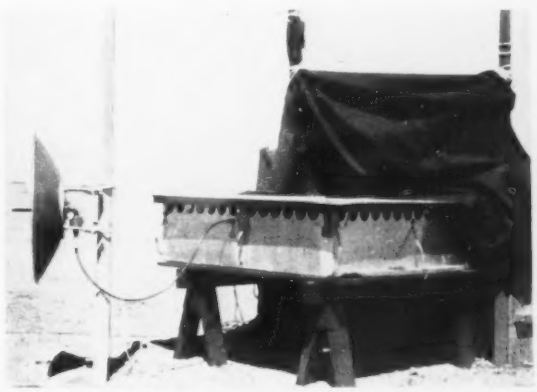
The distance between the two VHF receivers was measured with three standard invar 50-meter tapes that had been calibrated in the Bureau's length laboratory. The actual survey and calculation of the distance was carried out by means of U. S. Coast and Geodetic Survey techniques. The standard deviation of the measurements of the distance was two parts in 10^6.

The final value of 299,795.1±3.1 km/sec for the velocity of propagation of radio waves in free space was determined as a weighted average of 110 independent measurements made during 10 days. The uncertainty of ±3.1 km/sec includes an estimated systematic error of ±0.7 km/sec in addition to a 95 percent confidence interval for the mean value of the measurements.

[1] *Birge, R. T., Rev. Modern Phys.* **13**, *233 (1941).*

[2] *DuMond, J. W., and Cohen, E. R., Rev. Modern Phys.* **25**, *691 (1953).*

For further technical details, see Plyler, E. K., Blaine, L. R., and Connor, W. S., The velocity of light from the molecular constants of carbon monoxide, *J. Opt. Soc. Am. (February 1955).*



One of two metal enclosures which housed the VHF radio receivers used in measuring the velocity of electromagnetic waves by phase-shift method. Enclosure also contains 1-kc band-pass filters, UHF relay-link, equipment and a set of storage cells for battery operation of the equipment. UHF transmitting antenna and reflector are visible at left.

NBS Advisory Committees Established

DURING THE PAST YEAR, 12 technical area advisory committees have been established to provide a direct, continuing link between the National Bureau of Standards and the organized science and technology of the Nation. Nine scientific and engineering societies have nominated advisory committees to the Bureau in the fields of physics, chemistry, mathematics, metallurgy, ceramics, and electrical, radio, civil, and mechanical engineering. In addition, the National Conference on Weights and Measures, the American Society for Testing Materials, and the American Standards Association have designated groups at the Bureau's request to advise in their areas of special interest.

These committees, which will supplement the Bureau's Statutory Visiting Committee, have been set up as a result of recommendations made by the Ad Hoc Evaluation Committee appointed by the Secretary of Commerce in April 1953 to evaluate the Bureau's program in relation to national needs. Under the chairmanship of Dr. Mervin J. Kelly, President of Bell Telephone Laboratories, the Evaluation Committee conducted a comprehensive survey and reported in October 1953 that the Bureau's statutory functions were well conceived and its operations generally sound. At the same time, however, the Committee recognized the desirability of some means whereby the needs of the Nation's scientific and engineering societies could be expressed and transmitted to the Bureau for implementation in its program.

In general, the functions of the advisory committees are twofold. First, each committee plays an external role, in which its members represent formally the interests and needs of their society and interpret its point of view in terms of the NBS program. To encourage objectivity in this function, the advisors are nominated by their society and serve as a committee of the society rather than a committee of the Bureau.

The second function, which might be called an internal one, involves assistance to the Bureau on more detailed problems of program formulation and evaluation. Here the committee members work in small groups or panels directly with the heads of the Bureau's various laboratories. Specific advice is given on technical procedures, and suggestions may be made regarding the initiation or possible abandonment of certain lines of endeavor.

The advisory committees have now selected their chairmen and have held one or more meetings at the Bureau. The general areas of interest of the various groups have been largely delineated, and some recommendations have been made. It is felt that the special committees will prove a valuable source of consultation and stimulation which will strengthen the ties of the Bureau with American science and industry.

The advisory committee appointed by the American Institute of Physics is concerned with all phases of the Bureau's work in the general field of physics, which

Dr. M. J. Kelly, President, Bell Telephone Laboratories and Chairman, Ad Hoc Committee for the Evaluation of NBS; also recently appointed Chairman of the Bureau's Visiting Committee.

constitutes a major segment of the NBS research and development program. However, particular interest has been shown in the work of three NBS divisions—Optics and Metrology, Heat and Power, and Atomic and Radiation Physics—in which much of the physics research is concentrated, and the committee has divided itself into panels to review their programs. Typical activities in these divisions include studies of multimillion volt X-rays, development of standards of radioactive emission, determination of atomic and nuclear constants, research into the properties of matter near absolute zero, development of temperature standards for jet engines, development of color standards for the petroleum industry, and investigation of semiconducting materials for rectifiers and transistors. The committee is under the chairmanship of Professor Fred Seitz of the University of Illinois.

The American Chemical Society has appointed a committee, under the chairmanship of Professor N. Howell Furman of Princeton University, to render advisory services in connection with the Bureau's programs in chemistry. While work relating to chemistry is distributed among several of the Bureau's technical and scientific divisions, this committee will concern itself chiefly with the work of two NBS divisions: Chemistry, and Organic and Fibrous Materials. The Chemistry Division conducts basic and applied research in physical, analytical, organic, and inorganic chemistry. Representative activities include the development of new methods of chemical analysis, studies of the nature and causes of chemical reactions, determination of the physical constants of substances of interest to science and industry, research on methods of electrodeposition, and development of specifications for commodities used extensively by the Government. The Division of Organic and Fibrous Materials investigates rubber, plastics, textiles, leathers, and papers—polymeric materials whose characteristic properties are due to the long, chainlike structure of their molecules.

The fundamental properties of high polymers, both natural and synthetic, are studied to provide more adequate methods and equipment for developing and evaluating commercial products composed of these materials.

Another division of the Bureau which does a large amount of work in applied chemistry is the Mineral Products Division. This division is engaged in research in the general field of nonmetallic mineral products—ceramic coatings for high-temperature use in jet engines, optical glass, refractories, concreting materials, porcelain, pottery, lime and gypsum. Object of the program is to obtain the information on the physical and chemical properties of these materials which is needed for their efficient application in commerce, industry, and national defense. An advisory committee appointed by the American Ceramic Society will concern itself with the work of this division. Mr. R. E. Birch of the Harbison-Walker Refractories Company is its chairman.

NBS activities in applied mathematics are to be considered by an advisory group nominated by the Policy Committee for Mathematics. Dean Mina Rees of Hunter College is chairman. Applied mathematics at the Bureau is chiefly concerned with the development and utilization of new and more efficient mathematical tools for conducting scientific research, with the application of advanced mathematical techniques to problems throughout the Bureau, and with assistance to other Government agencies. Much of the mathematical research carried on at the Bureau is basic to the formulation, analysis, and solution of problems by means of high-speed electronic computers. The mathematics advisory group has also shown interest in some other areas, such as hydraulics, where mathematics is an important tool.

The American Institute of Electrical Engineers has appointed an advisory committee, under the chairmanship of Dr. Ralph Bown of Bell Telephone Laboratories, to consider programs in electricity and electronics. Work in electricity is primarily concerned with development and improvement of standards and methods of measurement for all electrical quantities. Research in electronics at NBS is directed toward obtaining knowledge of basic electronic phenomena and the properties of materials of potential significance to electronics. Developmental work in the electronics field includes not only the design of circuitry for the performance of new functions—such as various components of high-speed electronic computers—but also the broader phases of fabrication technology by which optimum designs for electronic equipment may be achieved.

NBS Technical Advisory Committees

American Institute of Electrical Engineers	Institute of Radio Engineers	American Institute of Physics *
Dr. Ralph Bown, Bell Telephone Labs. Dr. C. G. Suits, General Electric Co. Dean F. E. Terman, Stanford Univ. Dr. E. W. Engstrom, Radio Corp. of Am. Mr. Robert C. Sprague, Sprague Electric Co. Dr. J. A. Hutcheson, Westinghouse Electric Corp.	Dr. A. W. Straiton, Univ. of Texas. Dean F. E. Terman, Stanford Univ. Prof. Henry G. Booker, Cornell Univ. Mr. Harold O. Peterson, Radio Corp. of Am. Mr. Stuart L. Bailey, Jansky & Bailey Dean William L. Everitt, Univ. of Illinois	Prof. F. Seitz, Univ. of Illinois Prof. J. W. Beams, Univ. of Virginia Prof. D. M. Dennison, Univ. of Michigan Dr. E. M. Purcell, Harvard Univ. Prof. J. A. Bearden, Johns Hopkins Univ. Dr. M Deutsch, M. I. T. Mr. Hale Sabine, Celotex Corp. Prof. R. B. Lindsay, Brown Univ. Dean R. A. Sawyer, Univ. of Michigan
Policy Committee for Mathematics	**American Institute of Mining and Metallurgical Engineers**	**American Chemical Society**
Dean Mina Reese, Hunter Col. Prof. Philip M. Morse, M. I. T. Dr. Edward Teller, Univ. of California Prof. David Blackwell, Howard Univ. Prof. A. H. Taub, Univ. of Illinois Prof. Mark Kac, Cornell Univ.	Dr. Walter A. Dean, Aluminum Co. of Am. Mr. Earle E. Schumacher, Bell Telephone Labs. Dr. Maxwell Gensamer, Columbia Univ. Mr. Clarence E. Sims, Battelle Memorial Inst. Dr. E. C. Smith, Republic Steel Corp. Dr. Cyril S. Smith, Univ. of Chicago	Prof. N. Howell Furman, Princeton Univ. Prof. C. S. Marvel, Univ. of Illinois Dr. Milton Harris, Harris Research Labs. Dr. C. F. Rassweiler, Johns Manville Corp. Dr. J. R. Ruhoff, Mallinckrodt Chemical Works Dr. Norman A. Shepard, American Cyanamid Co.
American Ceramic Society	**American Society of Mechanical Engineers**	**National Conference on Weights and Measures**
Mr. R. E. Birch, Herbison-Walker Refractories Co. Dr. K. C. Lyon, Indiana Glass Co. Mr. E. P. McNamara, Cambridge Tile Co. Dean Elburt Osborn, Pennsylvania State Univ. Mr. Wayne Deringer, A. O. Smith Corp. Dr. Allan Bates, Portland Cement Assoc.	Dr. James W. Parker, Detroit Edison Co. Prof. Dana Young, Yale Univ. Prof. S. R. Beitler, Ohio State Univ. Prof. C. Harold Berry, Harvard Univ. Prof. A. P. Colburn, Univ. of Delaware Mr. Paul V. Miller, Taft Pierce Manufacturing Co.	Mr. John P. McBride, Director of Standards, State of Mass. Mr. W. M. Harks, Bowser Inc. Mr. Burns H. Dreese, Hobart Manufacturing Co. Mr. Alvin V. Hokanson, Assn. of Retail Grocers Mr. Charles M. Fuller, Sealer, Los Angeles Co. Mr. Harry J. Kennedy, Continental Oil Co.
American Society of Civil Engineers	**American Standards Association**	**American Society for Testing Materials**
Dr. G. H. Hickox, Nat. Science Found. Dr. A. T. Ippen, M. I. T. Mr. Raymond C. Reese, Toledo, Ohio	Mr. Roger E. Gay, Bristol Brass Corp. Mr. John R. Townsend, Sandia Corp. Mr. Arthur S. Johnson, American Mutual Liability Ins. Vice Adm. (ret.) G. F. Hussey, Jr., American Standards Assn. Mr. Cyril Ainsworth, American Standards Assn.	Mr. Norman L. Mochel, Westinghouse Electric Corp. Dr. Allan Bates, Portland Cement Assn. Mr. T. A. Boyd, General Motors Corp. Mr. Aiken W. Fisher, Fisher Scientific Co. Mr. R. E. Peterson, Westinghouse Research Labs.

* Dr. L. D. Marinelli has been appointed by the American College of Roentgenology to consult with this committee on radiological problems at the request of the A. I. P.

An advisory committee appointed by the Institute of Radio Engineers has as its principal interest the NBS Central Radio Propagation Laboratory in Boulder, Colorado. Chairman of this group is Dr. A. W. Straiton, Electrical Engineering Research Laboratory, University of Texas. The CRPL, consisting of three divisions of the Bureau, is the central agency of the Government for research in radio propagation. Its program involves basic and applied research in radio physics, geophysical phenomena, and extraterrestrial radiation from the sun and stars. The laboratory investigates phenomena affecting the propagation of radio waves, develops primary standards and measurement techniques for electrical quantities at radio frequencies, and prepares radio propagation predictions necessary for effective radio communications.

In metallurgy the Bureau determines the structure and properties of metals and alloys and studies the effect of various factors on structure and behavior under normal and abnormal conditions of service. In general, the program seeks a better understanding of the properties of metals in order that new or improved metals and alloys may be developed for better performance in established uses and to meet the needs of new applications. The program in metallurgy is reviewed by a committee designated by the American Institute of Mining and Metallurgical Engineers with Dr. Walter A. Dean of the Aluminum Company of America as chairman.

Because of considerable overlapping of interests, the advisory committees from the American Society of Civil Engineers and the American Society of Mechanical Engineers plan to work very closely with each other. The two groups have been holding joint meetings at the Bureau. Among the interests of the ASCE committee is the Bureau's work in building technology. In this field the Bureau conducts laboratory research on technical problems relating to building construction and maintenance, and assists Government and industry in applying scientific principles and data to building design. The ASME advisory group's many interests include the Bureau's program in mechanics, which involves work in aerodynamics and in structural properties of materials. Other programs of concern to this group include thermodynamics, automotive and aircraft fuels and lubricants, and the length standardization and gage calibration work which is basic to the control of dimensions in mass production. Chairmen of the ASME and ASCE groups are Dr. James W. Parker of the Detroit Edison Co. and Dr. G. H. Hickox of the National Science Foundation, respectively.

The committee appointed by the National Conference on Weights and Measures will consider the program of the NBS Office of Weights and Measures. This office coordinates the weights and measures activities of State and local governments with the general purpose of raising the standards of efficiency and coverage, and increasing the degree of uniformity throughout the country. Cochairmen of the advisory group are Mr. John P. McBride, Massachusetts State Director of Standards and Necessaries of Life, and Mr. W. M. Harks, Vice President, Bowser Inc. This committee includes State weights and measures officials as well as representatives of business and industry.

The advisory groups designated by the American Standards Association and the American Society for Testing Materials have recently held organizational meetings. It is expected that these two committees will concern themselves principally with the Bureau's work in the development of engineering standards, building and safety codes, and purchase specifications. Chairmen of the American Standards Association and American Society for Testing Materials committees are Mr. R. E. Gay and Mr. N. L. Mochel, respectively.

Radiation Balance

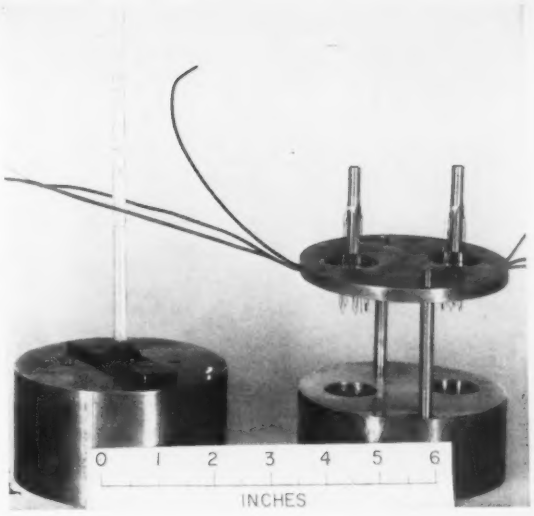
A RADIATION-BALANCE MICROCALORIMETER recently developed by W. B. Mann of the Bureau, precisely determines the emission rate of low-activity radioactive sources. The instrument does this by measuring the minute amounts of heat-energy which accompany radioactive emission. The device is extremely compact and requires a relatively short time to complete a determination. It can be used to determine the intensity of a single source or to compare two sources of nearly equivalent energy emission.

A primary function of NBS is the custody and maintenance of the national standards of physical measurement to meet the needs of science and industry. The Bureau's first standard of radioactivity was brought to this country by Marie Curie in 1913. Subsequently two Hönigschmid radium standards were acquired to calibrate and compare all of the radium sources produced and sold in this country. With the development of atomic energy and the tremendously increased use of radioisotopes, the demand for NBS certification of radioactive sources increased appreciably. To accommodate this new work, the radiation balance was developed and investigated as a possible supplement to existing instruments. It is capable of rapid, accurate determinations, and is expected to aid materially in the certification work.

A calorimeter embodying the principles used in the NBS radiation balance was first described by H. L. Callendar in 1910. With this calorimeter, which he called a radio-balance, Callendar made measurements of solar radiation and also carried out a somewhat preliminary measurement of the energy emitted in unit time from a sealed source of radon. Since that time, apart from a determination of the Stefan-Boltzmann radiation constant by Hoare in the early 1930's, no other reference to the radio-balance has occurred in scientific literature.

For measurement of radioactive emission a cup form of the radio balance was designed at NBS. This instrument consists essentially of two cups, the tem-

One of the present group of NBS radiation balances shows the two gold source cups and their thermopiles at right. Large copper block and thermometer at left are placed on top when the balance is assembled for operation.



peratures of which are balanced against each other by means of two thermopiles arranged around the equator of each cup and connected in opposition through a sensitive galvanometer. Thus, when there is no difference in temperature between the cups, there will be no deflection of the galvanometer.

The thermopiles were constructed with the help of a number of lucite annuli of $^3/_8$ in. external diameter, $^7/_{32}$ in. internal diameter, and $^3/_{32}$ in. thick. Twelve small holes were drilled through each of the annuli parallel to the axis and at 30° intervals. Alternate 0.010 in. diameter constantan and 0.012 in. diameter chromel wires were then threaded through the 12 holes of 6 of these annuli in series and held in place with glyptal cement. A thermopile was obtained by cutting the wires midway between the annuli and soldering adjacent constantan and chromel wires of each annuli in such a manner as to give each a continuous circuit.

A junction of two dissimilar metals, known as a Peltier junction, is soldered to the bottom of each cup. When an electric current is passed through a Peltier junction, heat is either absorbed or generated depending on the direction of the current.

The two junctions are connected in series in such a way that when a current is passed through them one junction cools and the other heats. A radioactive source is placed in cup A, and a current is passed through the junctions in a direction such that Peltier cooling occurs in the junction below A and Peltier heating in the junction below cup B. The current can be adjusted (provided that the source of radioactivity has an energy emission below a certain calculable maximum value) so as partially to balance the energy emission in A with Peltier cooling. With the addition of Peltier heating in B, it is possible to achieve a temperature balance between A and B.

When this balance is achieved, there is normally only a small residual galvanometer deflection. Since the temperature of cup A is now very nearly equal to that of cup B, the heat losses from the cups, which occur chiefly along the thermopile leads, are essentially equal and compensatory.

This technique may also be used to compare two radioactive sources and can, in fact, be used to compare two nearly equal sources without the use of Peltier cooling or heating at all. When the energy emission value of a single source is required, it is desirable to use a similar dummy source in the second cup in order that the thermal conditions in the two cups may be essentially the same.

To measure absolute values of radioactive emission, the radiation balance is first calibrated by determining the magnitude of the Peltier effect in the junctions soldered to the bottom of each cup. For this purpose, two small accurately calibrated resistance coils (R and r) were wound on a platinum core to simulate the thermal conductivity of the platinum-iridium needles. The coils are connected in series with the Peltier junctions, so that the same current flows through the coils and the junctions. One coil is then inserted into each cup of the radiation balance, the current is adjusted in magnitude and direction to obtain balance, and the value of the current is determined.

When the galvanometer balance is achieved, a condition exists such that

$$i^2(R-r)=2iP,$$

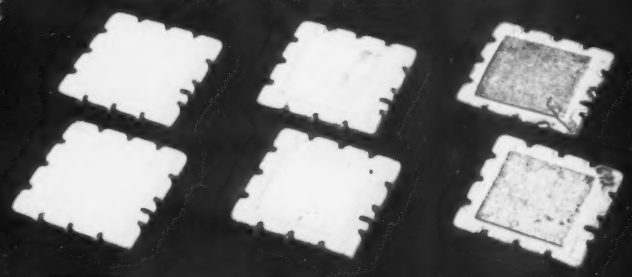
where i is the current flowing through the coils and the junctions, and R and r designate the resistances of the two coils. The Peltier effect P can be determined directly from this equation.

For the absolute measurement of the energy emission of a radioactive material, the source to be measured is placed in one cup, and a dummy is placed in the other. When the Peltier current has been adjusted to give a thermopile galvanometer balance, the difference in the energy emission from the sources is equal to the product of twice the current and the Peltier coefficient. Since the energy emission from the dummy is zero, the energy difference is equal in value to the emission of the radioactive source.

A number of radiation balances have now been constructed at NBS, and their application to the measurement of the energy emission from radium has been studied. One of these instruments, with cups of gold, has been used to compare the U. S. and British primary radium standards with the Candian national radium standard. With this radiation balance, the standard deviation of the results was only 0.13 percent.

The Bureau's radiation balances also have been used to measure the energy output of commercial radium preparations. The instruments are currently being applied to the determination of the branching ratio in the decay of polonium-210 and to the preparation of NBS tritium standards.

RECENT ADVANCES IN ELECTRONIC PROCESS TECHNOLOGY



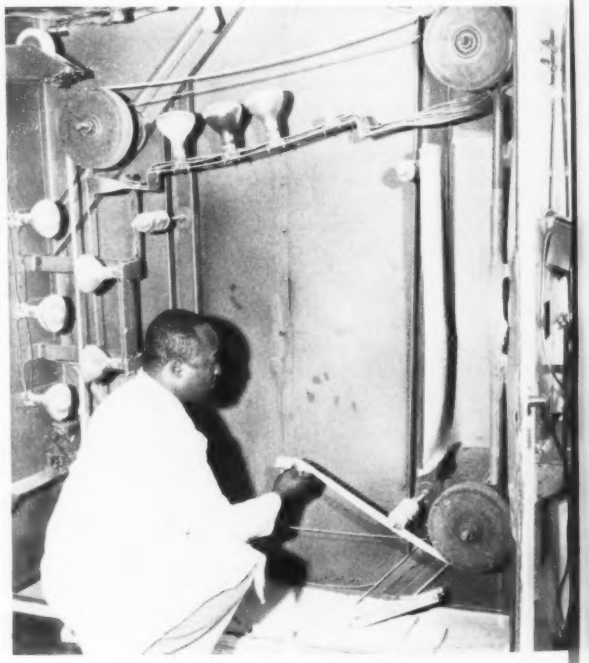
MDE–MPE tape capacitors in stages of production. Wafers at left are cured steatite blanks of same general type used in MDE–MPE system. Silver pattern that forms one electrode of capacitor has been applied to two wafers in the center. In wafers at right, adhesive dielectric-coated tape is cut into squares slightly larger than the silver contact and then pressed down onto the wafers. After curing, the capacitor is ready to be assembled into a module with other wafers such as that shown at top left.

SINCE the announcement of a new system for the mechanized production of electronics in 1953, the National Bureau of Standards has developed additional compatible components and techniques under the sponsorship of the Navy Bureau of Aeronautics. Recent advances achieved by NBS in electronic process technology include an adhesive tape capacitor, a "chip" resistor, and a method for applying pyrolytic carbon resistors. Developed by B. L. Davis of the Bureau's process technology laboratory, these components and techniques should do much to increase the versatility and applicability of electronic equipment manufactured by automatic production lines.

The development of systems for Modular Design of Electronics and Mechanized Production of Electronics (MDE–MPE), formerly code-named Project Tinkertoy, was begun by the Bureau with the cooperation of several industrial companies under the sponsorship of the Navy Bureau of Aeronautics as an industrial preparedness measure. The MDE–MPE system starts with raw or semiprocessed materials and automatically manufactures ceramic base wafers, dielectric elements for capacitors and adhesive tape resistors; prints conducting circuits and capacitors; and mounts resistors, capacitors and other component parts on standard, uniform steatite wafers. The wafers are stacked like building blocks to form modules that perform all the functions of one or more electronic stages. The pilot plant, operated by a commercial contractor, incorporates the principles of this system. The plant was designed to produce 1,000 finished and inspected modules per hour.

The Tape Capacitor

The self-adhesive tape capacitor is designed specifically for application to the ceramic wafer by MDE–MPE machine techniques. It is manufactured in much the same manner as the NBS adhesive-tape resistor.[1] A conducting tape, coated on one side with a dielectric, provides one element of the capacitor. The other element is a silver pattern printed and fired on the wafer. It is now possible to apply an adhesive-tape



In this chamber electrically conducting solution is sprayed on one side of tape, dried, and then sprayed on other side. When cured, dielectric formulation is sprayed on one side of tape. It is then ready to be used as one element of the capacitor. Spray unit can be seen at far right.

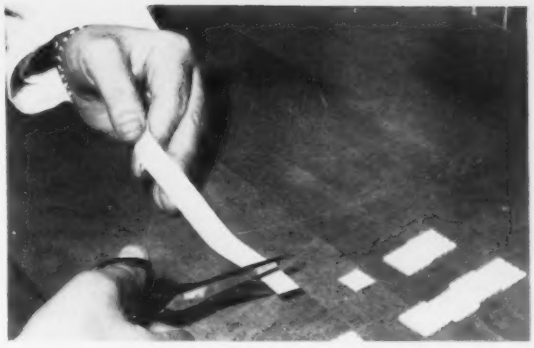
Application of adhesive tape capacitor to wafer. Although shown here as a manual operation for demonstration purposes, it is normally applied by machine.

resistor to one side of a wafer and an adhesive-tape capacitor to the other side.

The materials required for the manufacture of tape capacitors are a heat-resisting asbestos paper tape, silver flake, silicone resin, butyl cellosolve, a powdered high-K titanate body, *n*-hexane, and epoxide resin. The electrically-conducting formulation (a mixture of the silver flake, silicone resin, and solvent) is ground in a ball mill. The mixture is sprayed on a loop of tape 1¼ in. wide, allowed to dry thoroughly, and then sprayed on the other side. When cured, the metallized tape is conductive along each side and from one side to the other. After slitting along the center to form two ⅝-in tapes, it is ready for application to the dielectric film. A roll of tape 19 ft long will produce about 350 capacitors.

The dielectric formulation is composed of high-K titanate body that has been pulverized in a ball mill with *n*-hexane until the particle size is about 1 to 2 microns, after which the slurry is allowed to evaporate under a hood. The ground titanate body is mixed with epoxide resin and further ball-milled. This tacky dielectric mixture is then sprayed on the metallized base tape in various thicknesses determined by the number of passes the tape makes in front of the spray gun. Thicker applications, of course, make capacitors of lower value.

The silver pattern that forms one electrode of the capacitor is applied to the steatite wafer by means of a screen press. It is then dried and fired onto the ceramic. The adhesive dielectric-coated tape that forms the other electrode is cut into squares slightly larger than the silver contact and pressed down on it. A narrow conductive strip, similar to resistor tape but with a conductivity of approximately 0.02 ohm per half inch, is laid down between a contact on the edge of the wafer and the top side of the capacitor. The



complete assembly is then cured by placing it in an oven at room temperature, raising it to 225° C over a period of one-half hour, and holding the temperature at 225° C for 45 minutes.

Capacitors of higher values can be manufactured by applying a number of layers of tape, one on top of another, with appropriate connections to the edge of the wafer. Smaller capacitors can be made by reducing the area of the silver pattern printed on the wafer, or by increasing the thickness of the dielectric layer. For typical values, see table 1.

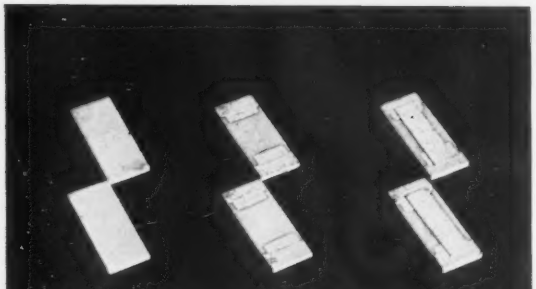
Second element of capacitor is a silver pattern printed on an MDE-MPE wafer. Elements may be printed on either or both sides, depending on requirements of finished circuit. An adhesive tape resistor can be applied to opposite side of wafer instead of a capacitor, if desired.

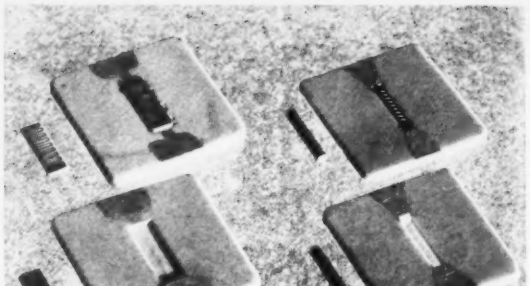
Shelf life tests indicate that the capacitance changes no more than 1 percent during the first month after manufacture, and that there is no change in the dissipation factor, which averages 0.7 percent at 1 kc. However, the capacitance does change somewhat with temperature, −3 percent from 25° to 85° C, and −15 percent from 25° to −55° C. In a load life test, a few capacitors shorted out, but otherwise only negligible changes occurred in capacitance and dissipation factor.

The "Chip" Resistor

The "chip" resistor is made by applying self-adhesive resistor tape to a small chip of ceramic material. This resistor is not for use in the regular quantity production of modules, but aids the electronic design engineer in studying new modular circuits which are still in the "breadboard" stage or in producing prototype equipments for evaluation. The chip is inserted into a circuit simply by soldering it to the appropriate connections on a standard wafer.

The precured resistor tape is manufactured automatically by the usual MDE–MPE techniques but is applied to a chip of cured steatite about 0.600 by 0.225 in. instead of the standard MDE–MPE wafer. A prototype machine developed in the NBS laboratories





Left: **Samples of the NBS chip resistor in various stages of manufacture. This resistor is not for use in the regular quantity production of modules, but instead aids the electronic design engineer in studying new modular circuits.** ***Right:*** **Pyrolytic carbon resistor can be made in either flat or round shapes. The ceramic forms covered with a carbon film are either spirally ground (in the case of the round form) or sandblasted in a zig-zag path (in the case of the flat form) to increase the path length and thus to increase the resistance of the units. Two wafer models with depressions for receiving the resistors and two finished wafers with the resistors inserted are shown.**

mounts the resistor on the chip. The chip, with its tinned and silvered connecting tabs already fired onto each end, is automatically oriented properly in a shallow die. A roll of tape of the desired resistance value is fed into the machine and is die cut to a size of 0.5 by 0.125 in. to overlap the metallized tabs on each end. The machine then presses the cut tape, adhesive side down, onto the ceramic chip. When this operation is completed, the chip resistor is ejected from the machine into a hopper and is ready to be cured. The final machine will be entirely automatic, will require no attention other than supplying it with steatite chips and resistor tape, and will be capable of manufacturing 1,000 chip resistors per hour.

The Pyrolytic Carbon Resistor

The pyrolytic carbon resistor [2] is a miniature component made by a process developed by the Bell Telephone Laboratories. Because this resistor may be manufactured in large quantities to close tolerances, the Bureau has adapted it to the MDE–MPE methods by inserting it in a specially designed wafer to produce a unit that is wholly compatible with other MDE–MPE units. The resistors are either flat or cylindrical and are about $\frac{5}{8}$ in. long by $\frac{1}{8}$ in. wide or $\frac{1}{16}$ in. in diameter.

Although not yet in regular production, these carbon-film resistors are being manufactured for small production runs under license from the Western Electric Company. They are made by cracking or decomposing methane gas in a high temperature environment which also contains the miniature ceramic forms. Pure carbon is deposited on the ceramic in accurately controlled thicknesses. The coated forms are then either grooved or spiralled mechanically to increase the electrical path length and to decrease the path cross section. Accurate control of resistance is achieved in this way, and the finished resistor is within 2 percent of its design value.

An MDE–MPE wafer having an appropriately shaped depression receives the carbon resistor. The depression has printed conducting paths on each end to provide connection from the resistor terminals to the riser wires of the completed module. After the resistor is inserted into the wafer, it is terminated with a silver thermo-setting resin mixture and cured at 150° C for 2 hours or at 200° C for one-half hour. It is then ready to be assembled, via the automatic production line, into a module with other electronic components.

TABLE 1. *NBS tape capacitor*

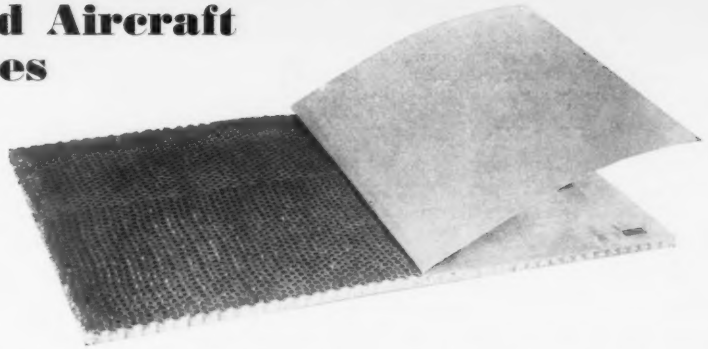
Preliminary breakdown voltage ratings	
Capacitor values	Voltage breakdown DC—flash test
μμf	*Volts*
500	Greater than 600
750	Greater than 600
1,000	600
1,250	500
1,500	400
1,750	300
2,000	200

[1] A self-adhesive high temperature tape resistor, *Tech. News Bull.*, **35**, *100 (July 1951)*, Precured NBS tape resistor, *Tech. News Bull.*, **36**, *110 (July 1952)*, An adhesive tape-resistor system, *NBS Circular 503, Government Printing Office, 30 cents.*

[2] Fixed resistors for use in communications equipment, *Proc. Inst. Elec. Eng.* **96**, *Part III (Radio & Comm. Eng.) No. 41 (May 1949)*.

For further technical details, see PROJECT TINKERTOY, *Tech. News Bull.* **37**, *161 (Nov. 1953)*; Vol. I—Summary MDE and MPE, *PB111275*; Vol. II—Conversion from conventional design to MDE, *PB111276*; Vol. III—Hand fabrication techniques, *PB111277*; Vol. IV—Mechanized production of electronics (MPE), *PB111278*; Vol. V—Manufacturing cost determination, *PB111315*. *These five volumes are available from: Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C.*

Adhesive Bonded Aircraft Structures



One type of aircraft adhesive-bonded structural component tested at NBS to secure a better understanding of such structures. This is an aluminum honeycomb sandwich panel, with one sheet partially removed to show core.

THE DEVELOPMENT of high strength metal-to-metal adhesives in recent years has made possible an entirely different approach to the fabrication of metal aircraft structures. Certain economic, structural, and weight-saving advantages offered by the substitution of adhesives for rivets have already been realized by several aircraft companies in the fabrication of structural components, and the widespread adoption of this method in the future has become a definite possibility. To secure a better understanding of the behavior of adhesive bonded aircraft structures, Wilhelmina D. Kroll and Leonard Mordfin of the Bureau have conducted investigations under the sponsorship of the National Advisory Committee for Aeronautics and the Navy Bureau of Aeronautics.

The use of adhesives for bonding aircraft structural components is not new. During World War I casein was used in the gluing of wooden aircraft structures. The synthetic glues were used extensively for many all-wood and some wood-metal joints for aircraft in World War II. Finally, the development of high strength resin and resin-rubber adhesives made possible the bonding of all-metal aircraft structural components. Two such components are the sandwich panel and the sheet-stringer panel.

A sandwich panel consists of three laminations bonded together. The outer two laminations, or facings, are made of strong, stiff, sheet materials which usually determine the elastic and strength properties of the panel. The central layer, or core, is made of a light material and serves only to separate the facings and to restrain them from becoming elastically unstable. The value of sandwich construction lies in its relatively light weight and in the high bending strength and stiffness it possesses as a result of its high ratio of cross-sectional moment of inertia to weight. Another desirable advantage (from the aerodynamic standpoint) is the absence of rivet heads.

One of the applications of sandwich construction is in the fabrication of skins and floors for pressurized aircraft fuselages where the sandwich construction is subjected both to lateral pressures and to axial loads simultaneously. The Bureau's engineering mechanics laboratories conducted an investigation for the NACA to determine the strength of sandwich panels of various thicknesses under these combined axial and lateral loads.

The panels tested were about 30 inches long and 17 inches wide, with facings of either 0.025-inch or 0.032-inch 75S–T6 aluminum alloy sheet, and cores ½ or ¾ inches thick. The cores are honeycombs of 0.005-inch 2S–H aluminum foil and have a density of only 6.54 lb/ft^3.

The lateral pressures were applied by a rubberized fabric air bag and ranged from zero to 9.54 lb/in^2. The panels were simply supported in knife edge seats in a hydraulic testing machine which applies the axial load. All tests were carried to failure, and strain and deflection measurements were made periodically with SR–4 wire strain gages and dial gages, respectively.

The results of these tests were compared with values predicted from a theoretical analysis based on column theory. The analysis includes the effects of the strain energy stored in the faces of the panels by extension and by bending, and in the core by shear, but disregards the strain energy due to shear in the faces and to extension in the core parallel to the faces. Good agreement was obtained between theory and experiments for the flexural rigidity and for the failing loads under the various load combinations investigated. The theory was found to be conservative, however, in its prediction of axial strains and lateral deflections. The discrepancy was attributed to anticlastic bending, which was observed in the tests but does not enter into the column theory. Anticlastic bending produces a transverse curvature in a panel which increases its stiffness and thus reduces the strains and deflections for a given loading condition. The amount of anticlastic bending obtained in a panel increases with the lateral load and decreases with panel stiffness. Hence the agreement between experiment and theory was considerably closer for the stiffer panels tested and for the panels tested under the lesser lateral pressures. For a panel tested with zero lateral pressure, the agreement was excellent.

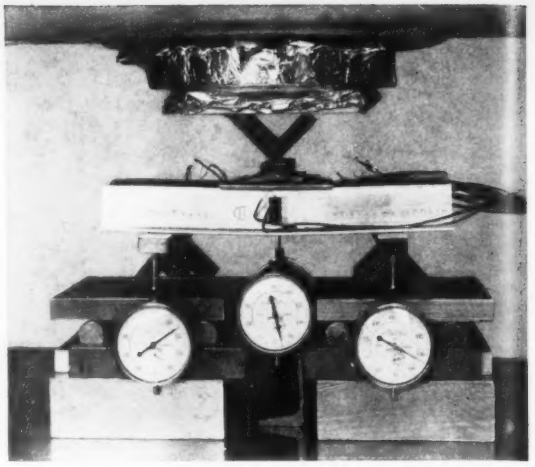
When a sandwich panel is attached to some other structural member, it may be necessary to transfer the loads from the member to the panel by means of a pin that fits into a reinforced hole in the panel. As part of an earlier research project conducted by NBS for the Navy Bureau of Aeronautics, a test was performed on a sandwich panel to determine the stress distribution near a reinforced circular hole in the panel that was loaded by a pin. The results indicate

Bonded sheet-stringer panel is bending test. Here, a concentrated load is applied midway between simple supports. In this type of construction, the sheets provide the outer skin of the airplane while the stiffeners add the necessary strength, stiffness, and stability.

that if the reinforcement is bonded to the sheet so that reinforcement and sheet act as an integral unit, then plane stress theory will predict the average elastic stresses in both sheet and reinforcement and also the changes in the hole diameter.

A more conventional type of aircraft structure to which adhesives have been applied is the sheet-stringer panel. Sheet-stringer construction, which comprises most of the outer skin of a conventional airplane, consists of a sheet with stiffeners attached longitudinally to one side. The sheet provides the necessary aerodynamic contour while the stiffeners, or stringers, add the necessary strength, stiffness and stability. The stringers often are angles or channels, but very frequently have cross sections resembling **Z**'s, **I**'s, or hats. In the past, the stringers were almost always riveted to the sheets. Two new innovations are the bonded sheet-stringer panel and the integrally machined sheet-stringer panel.

The Bureau tested 21 riveted and bonded sheet-stringer panels for the NACA to determine the relative merits of these two types of construction. The panels were fabricated from 75S–T6 aluminum alloy with five stringers each, spaced at 3½-inch intervals. Nine panels were riveted with a 1⅛-inch pitch, nine were bonded with an epoxy resin adhesive and three were bonded with a phenolic resin-rubber adhesive. Some



of the panels were tested in flat-end compression, others in compression with a concentrated load applied to one end of the center stringer, and the remainder in bending with a concentrated load applied midway between simple supports.

The results obtained in the tests show that the mechanical properties of both types of panels are comparable. The choice in any particular case would depend upon the specific designs being compared.

The primary advantage of bonded sheet-stringer panels over conventional panels which have one line of rivets per stringer is the increased sheet stability that is obtained by bonding. The broad area of attachment between sheet and stringers reduces the unsupported width of sheet, thus increasing the load necessary to produce buckling of the sheet between stringers. When buckling occurs, the broad area of attachment between sheet and stringers provides a greater effective sheet width. In addition, interrivet buckling and stress concentrations near the rivet heads which tend to produce buckling between stringers are eliminated.

The primary disadvantage of bonded sheet-stringer panels seems to be in the mode of failure in flat-end compression. When maximum load was reached in the tests, the bonded panels experienced almost complete destruction. The failure of the riveted panels, on the other hand, was confined to local buckling of sheet and stringers between rivets.

One of the most important factors restricting the universal acceptance of adhesive bonding for aircraft structures is the difficulty of properly inspecting bonded joints. Small changes in pressure, temperature, humidity, etc., in the fabricating process can produce imperfections which greatly decrease the strength of the joint, and can often be detected only by destruc-

Bonded sheet-stringer panel in axial flat-end compression test. This type of structure consists of a single sheet with stiffeners attached longitudinally to one side with an adhesive bond.

tive tests. These imperfections can be dangerous in modern high-speed aircraft which are designed with extremely high operating stresses. An important consideration, therefore, in the widespread application of bonding techniques is the development of either completely reliable fabrication procedures or of satisfactory nondestructive inspection procedures.

For further technical details, see W. D. Kroll, L. Mordfin, and W. A. Garland, Investigation of sandwich construction under lateral and axial loads, *NACA TN 3090 (Dec. 1953) ; L. Mordfin and I. E. Wilks,* Tests of bonded and riveted sheet-stringer panels, *NACA TN 3215 (June 1954) ; S. Levy and F. C. Smith,* Stress distribution near reinforced circular hole loaded by pin, *J. Research NBS* **42**, 397 (1949) RP1979.

Tenth International Conference on Weights and Measures

A NUMBER of important topics in the field of international standardization were considered by the Tenth General Conference on Weights and Measures meeting in Paris and Sèvres, France, October 5 to 14, 1954. Among the accomplishments of the Conference was the adoption of a new definition of the thermodynamic or absolute scale of temperature. Definite progress was reported on a project to redefine the standard meter in terms of a wavelength of monochromatic light from a single isotope, and the results of a recalibration of national standards of mass were considered. Other subjects under discussion included international comparison of electrical and photometric standards, redetermination of the force of gravity, intercomparison of national and international meter bars, definition of a more constant unit of time, and establishment of a standard value for normal atmospheric pressure.

The General Conference on Weights and Measures was established by treaty in 1875 and has held regular meetings at 6-year intervals since 1889, with the exception of interruptions due to the two World Wars. Of the 35 countries now belonging to the international organization, 32 appointed delegates or observers to the 1954 meeting, making a total of over 70 persons. Representatives of the United States, appointed by the Department of State, were Dr. Allen V. Astin, Director of the National Bureau of Standards, and Dr. E. C. Crittenden, consultant to the Bureau.

The Conference exercises general authority over a permanent International Committee of 18 members, which meets every 2 years. The Committee is responsible for directing all projects in metrology which the member-countries decide to undertake jointly, including the preservation of the international metric standards and other activities of the International Bureau of Weights and Measures at Sèvres. Besides providing a depository for international standards, the International Bureau carries on important research on many metrological problems, calibrates standards for other laboratories, both national and privately owned, and serves as a permanent secretariat for the International Committee and the General Conferences on Weights and Measures.

Because of the increasing diversity of measurement problems, four Advisory Committees have been set up to assist the International Committee on Weights and Measures in special fields. Each of these committees includes representatives of 7 or 8 national laboratories of the larger nations, as well as experts selected individually from smaller countries. The present Advisory Committees are concerned with measurements and standards in electricity, in photometry, and in thermometry, and with the project for a new definition of the meter. One of the purposes served by each General Conference is to inform member-countries of the progress made during the preceding 6-year interval by the permanent committees. The Conferences make decisions only on matters of principle or on changes of policy or practice.

Current work of the International Bureau was reported to the Conference by Charles Volet, Director of that Bureau, and by various members of his staff. In recent years the program has included comparisons of electrical and photometric standards from all of the larger countries. The work has shown a very satisfactory degree of uniformity in the new electrical units adopted in 1948 and good progress toward uniformity of photometric measurements on all types of lamps. Comparisons of end gages calibrated at various national laboratories by means of light waves indicate that such calibrations are now sufficiently precise to meet the ordinary needs of industry. But the measurements would not be entirely satisfactory for the establishment of basic standards because the results obtained in different countries might differ by as much as 0.05 micron on a 100-millimeter gage, that is, 5 parts in 10 million. Further research is needed to determine the causes of these discrepancies.

The International Bureau is engaged in a determination of the force of gravity at Sèvres. Preliminary results reported to the Conference indicate that the "Potsdam" basis for values of gravity, which has been generally used for half a century, is too large by 24 parts in a million. This agrees rather closely with determinations made at NBS and at the British National Physical Laboratory. However, additional determinations are under way in other laboratories. The International Committee has therefore agreed that values of the force of gravity involved in the determination of atmospheric pressures should conform to the classical Potsdam system until the Committee approves a change.

The International Bureau also reported the results of a recalibration of national kilogram standards which

was completed since the Ninth General Conference met in 1948. Of 24 standards originally certified in 1889, two showed no perceptible change, 14 had slight apparent increases in mass, and 8 showed small losses. The largest loss was 6 hundredths of a milligram, or 6 parts in 100 million. However, the weighings of 1889 were not sufficiently precise to make it certain that a change has occurred in any of the national standards except one. Kilogram No. 20, which belongs to the United States, appeared to have increased by 2 parts in 100 million between 1889 and 1948; but if this was a real change, nine-tenths of it occurred before 1937, when the last previous comparison was made.

An intercomparison of national and international meter bars is scheduled to begin in 1955. On this account, special attention was directed to the possibility of increasing the precision of observations by ruling new lines to replace the original lines on the bars distributed in 1889. It is believed that the lines can now be made so much better that the uncertainty of calibrations can be reduced by a factor of 10. Additional lines can also be ruled to give a length of one meter when the bar is at 20° C instead of 0°. Some countries have expressed a desire to have their meter standards reengraved to gain these advantages.

Definite progress was made on the project to redefine the meter unit in terms of the wavelength of a spectral line given by some single isotope. In September 1953, the Advisory Committee on Definition of the Meter had recommended that the proposed new definition be expressed in terms of a wavelength in vacuum, derived from the presently accepted wavelength of the red cadmium line in air under standard conditions. The conversion from air to vacuum wavelengths would be made in accordance with a formula for the dispersion of normal air adopted in 1952 by a Commission on Spectroscopy which is recognized as authoritative in the field. The International Committee approved this procedure for developing the new definition, but the actual adoption of a definition was not possible because four different isotopes have been proposed as suitable sources of light. Dr. W. F. Meggers, of the Bureau, several years ago proposed that the wavelength of the green line of mercury of mass number 198 be adopted. Workers at the German Physikalisch-Technische Bundesanstalt have advocated the use of a line in the spectrum of krypton 86, and this year they added xenon 136 as another possibility. Reports from the Russian Institute of Metrology have favored the use of cadmium, in the form of the single isotope, cadmium 114. The British National Physical Laboratory and the Canadian National Research Council Laboratory have studied some of these possibilities, but more information is needed concerning the spectral lines of the isotopes, the types of lamps to be used, and other operating conditions. Consequently, the Conference, while recognizing the progress made, urged the laboratories to expedite their work on monochromatic radiations in order that the next General Conference may reach a decision on the problem.

The Conference also considered the problem of defining a unit of time more constant in value than the mean solar second as now determined by current astronomical observations. This matter was brought up by a resolution adopted by the International Union of Astronomy in 1952. The astronomers point out that the length of the mean solar day has varied by as much as one part in 10 million during the period from 1870 to 1950, and there is no assurance that even larger variations will not occur. The Union therefore recommended that for highly precise data (such as the frequencies assigned for some radio signals) the second be taken as a fraction of a single specified year. However, because the formal resolution referred to a "sidereal" year when it should have said "tropical" year, the General Conference did not consider it advisable to act on the recommendation. Instead, it authorized the International Committee to decide the matter without waiting until another General Conference convenes. The second will presumably be defined as "the fraction 1/31,556,925.975 of the tropical year 1900.0".

In accordance with a recommendation of the Advisory Committee on Thermometry, the Conference adopted a new definition of the thermodynamic or absolute scale of temperature, assigning the triple point of water [1] with the exact value of 273.16° K as the sole fixed fundamental point of the scale. This method of defining the scale has been advocated in recent years by Professor W. F. Giauque of the University of California, but was originally suggested 100 years ago by Lord Kelvin. For this reason and because any changes in assigned temperatures resulting from the change in definition of the scale are not likely to be greater than the uncertainty of present measures, the name Kelvin is to be retained for the absolute temperature scale.

In response to a request from the International Organization for Standardization, the Conference considered the establishment of a standard value for normal atmospheric pressure. It was announced that the value adopted by the Ninth General Conference in the definition of the International Temperature Scale should be accepted for all purposes. This value is 1,013,250 dynes per square centimeter or, in the meter-kilogram-second system, 101,325 newtons per square meter.

A proposal for the establishment of a system of practical units for use by all countries had been submitted by the French government in 1948. This proposal gave rise to such diverse comments that the International Committee was unable to prepare a generally accepted revision. By a divided vote on some details, the Conference decided that as a basis for such a system the following units should be adopted: for length, the meter; for mass, the kilogram; for time, the second; for electric current, the ampere; for thermodynamic temperature, the degree Kelvin; for luminous intensity, the candela.

At the conclusion of the Conference, five new members were elected to the International Committee, bringing the membership up to the total of 18 as provided

[1] *The triple point of water is 0.01 degree above the ice point (0° C).*

by the Convention of the Meter. The vacancies were filled by representatives of Australia, Austria, Finland, the United Kingdom of Great Britain and Northern Ireland, and the United States of America. Dr. Allen V. Astin, Director of the National Bureau of Standards, is the new American member, succeeding Dr. E. C. Crittenden, who resigned at the close of the Conference.

Society of Rheology Meets at NBS

THE TECHNICAL SESSIONS of the 1954 meeting of the Society of Rheology were held on November 3, 4, and 5 at the National Bureau of Standards. A wide range of subjects was discussed ranging from "Determination of the Baking Value of Bread Doughs" to "Viscoelastic Density Changes in Glass."

Several papers reported current advances in the field of dynamic measurements and its application to solids and liquids. Dynamic properties of filled polystyrene were shown to yield important information regarding the effect of the filler and the adhesion between filler particles and the polymer. Preliminary results on dynamic compressibilities indicate a new approach in dynamic measurements. For high polymer solutions, dynamic data from different laboratories and instruments can be reduced to a single curve showing that material properties can be measured, independent of the instrument used.

Also reported was the concentration dependence of the polyisobutylene-decalin system, which has been given detailed study, and advances in the analysis of dynamic tests on viscoelastic materials. The importance of a generalized relation, which makes no assumption about the unknown behavior of the material, was emphasized.

The derivation of a new mechanical formula for the viscosity of gases was discussed, along with the possibility of extending its use to liquids. Also presented were recent researches on the transport phenomenon of gases and the use of acoustical measurements in the study of liquid structure.

Solid polymers, their rheology and their performance under various types of mechanical loading were discussed. Stress-strain relationships at impact velocities, elastic moduli as a measure of anisotropy, and diffusion-controlled stress relaxation of fibers were reviewed. Papers on plastic systems included contributions to the flow behavior of bitumens and heat effect in the flow of molten polymers. Two papers advanced a theory of non-Newtonian flow, based on Eyring's simple relaxation theory.

At an evening dinner meeting the Society heard an address by Dr. Alan T. Waterman, Director of the National Science Foundation. The 1954 Bingham Medal was also presented at this time to Dr. Turner Alfrey of the Dow Chemical Company.

In his address Dr. Waterman emphasized the need for an expanding program for the training of both researchers and secondary school teachers. He also stressed the need for an expanded effort in basic research, pointing out that this is a prime role of the National Science Foundation.

Publications of the National Bureau of Standards

Journal of Research of the National Bureau of Standards, volume **53,** number 6, December 1954 (RP2551 to RP2558 incl.). Annual subscription $4.00.

Technical News Bulletin, volume **38,** number 12, December 1954. 10 cents. Annual subscription $1.00.

CRPL–123. Basic Radio Propagation Predictions for March 1955. Three months in advance. Issued December 1954. 10 cents. Annual subscription $1.00.

Research Papers

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RP2551. Creep of high-purity nickel. William D. Jenkins, Thomas G. Digges, and Carl R. Johnson.

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A. V. ASTIN, *Director*

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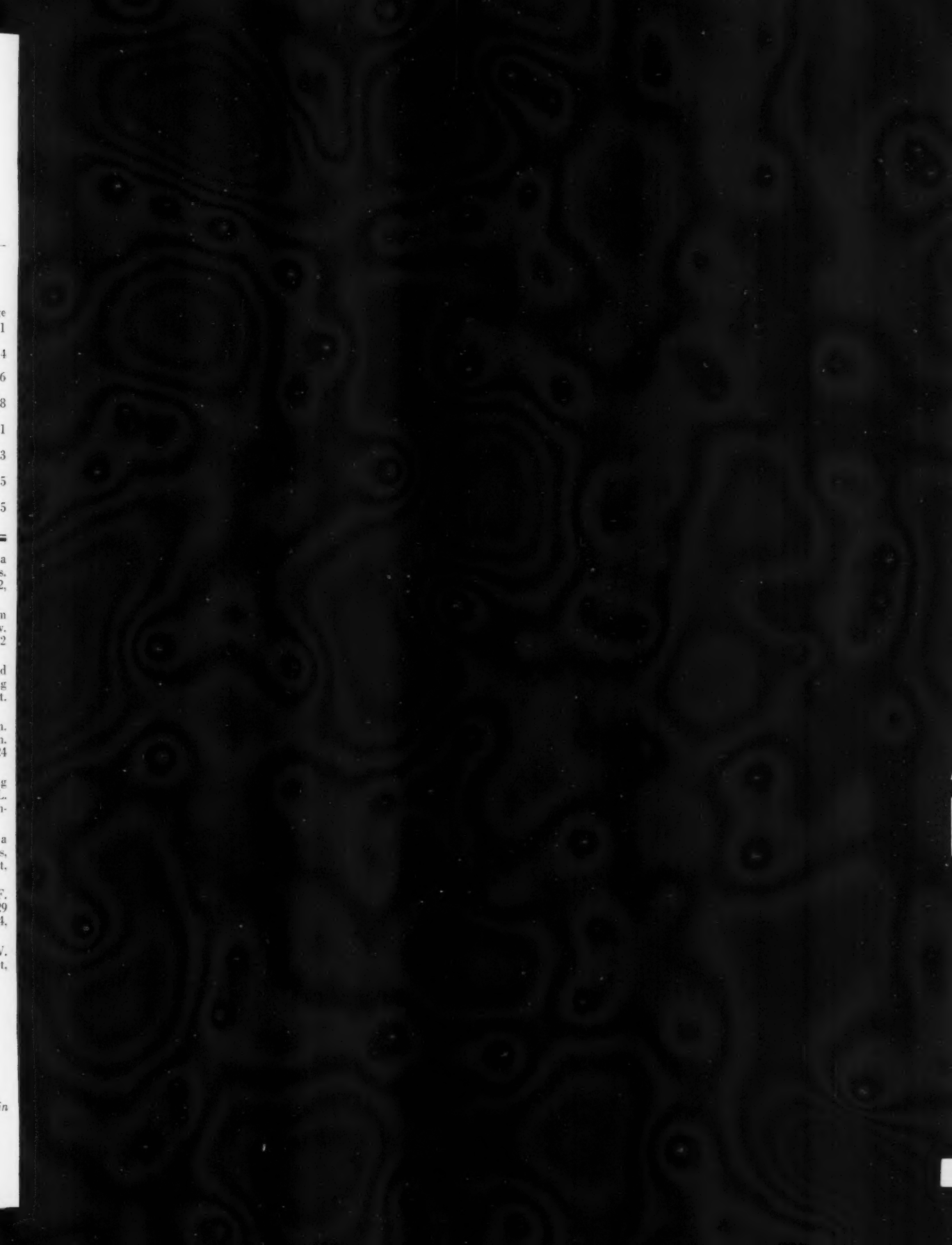
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